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ABSTRACT

This paper discusses research on the processes by which individuals progress toward expertise in scientific domains, focusing on the activity of constructing qualitative problem representations during solution of standard mechanics problems in physics. It includes information on: (1) descriptive analyses of problem-solving performance; (2) prescriptive models of problem-solving performance (which specify the knowledge required for novices to perform well on particular tasks); (3) a prescriptive theory of problem description (which specifies a procedure leading to construction of correct mechanics problem descriptions); (4) a theory of instruction which incorporates a particular model of learning-centered coaching referred to as "Evolving External Control Knowledge" (EECK); (5) the development of computer-oriented instructional materials based on the prescriptive theory and the EECK; and (6) preliminary results, focusing on possible relationships between changes in subjects' (N=9) performance and features of both the model of performance and the model of instruction. Results (among others) indicate that subjects seemed to be internalizing the notion of force as a kind of interaction and that the instructional materials are differentially appropriate for individuals at different stages of learning. (JN)

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Theory-based Instruction in Description of Mechanics Problems

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This work is part of a project sponsored by the Office of Naval Research, and builds upon earlier research that was supported by the National Science Foundation. Our aim is to bring about and study the processes by which individuals progress toward expertise in scientific domains. We are currently focussing on the activity of constructing qualitative problem representations during solution of standard mechanics problems in physics.

We are developing computer-based instructional materials based on particular cognitive theories--a prescriptive theory of performance, and a model of instruction--and we are studying closely students' knowledge and performance before, during, and after interaction with these materials.

In this paper we first give a little background for this work, and then summarize the theories of performance and of instruction. Next we briefly describe the instructional materials and present some preliminary results from observations of a small number of individuals who have used the materials thus far.

Descriptive Analyses of Problem-solving Performance

In the past two decades there has been an interesting shift in cognitive psychological research on problem solving, from the study of human performance in semantically simple task domains such as chess and symbolic logic (Newell & Simon, 1972), toward analysis of performance in increasingly complex subject-matter areas such as physics (Simon & Simon, 1978; Larkin, McDermott, Simon & Simon, 1980a, 1980b), geometry (Greeno, 1978), and arithmetic word problems (Riley, Greeno, & Heller, 1983). Many of the tasks which have been analyzed

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in these more recent studies are the same ones students typically encounter in school. A major source of insights into the nature of knowledge required for solving problems has been the comparison of performance by highly skilled "experts" with that by "novices." These studies have identified specific differences in the knowledge of skilled and less skilled individuals. One of the most significant findings in this literature is the observation that experts construct mental representations of the physical situations depicted in problem situations, representations which incorporate concepts and principles from physics, and use those representations to guide their solutions of the problems. On moderately difficult problems, experts perform an explicit "qualitative analysis" of the problem situation before generating any equations (Larkin, 1977, 1980). Experts tend to draw two kinds of sketches to represent a problem: diagrams representing the physical situation described in the problem, and more abstract diagrams representing the problem in terms of concepts from physics, such as force and energy. Larkin (1982) refers to these diagrams as "naive" and "scientific" representations.

What is particularly intriguing in these findings is the fact that the information in the abstract or scientific representations generated by experts is not mentioned anywhere in the problem statements. To "know physics," according to Simon and Simon (1978), individuals must have this ability to bring their knowledge of scientific concepts and laws to the situations they encounter--that is, to understand complex problem situations in terms of the laws of physics.

Novices, however, are unable to construct mental representations which impose theoretical structure on physical situations. In the absence of such knowledge, novices are left with only the superficial information that is explicitly provided in verbal and physical representations of the problem.

Novices tend to use an "algebraic" approach when solving problems, going directly from reading the problem statement to searching for formulas which contain variables that are wanted in the problem. Their solutions are not driven by an understanding of the problem, but rather are patched together from local matches between values in the problem and symbols in formulas.

Although novices do sometimes draw "scientific" diagrams during their problem solutions (Larkin, 1980), these diagrams frequently contain serious errors of commission as well as omission (Heller & Reif, 1984). In part, this is because students enter courses with naive intuitions and conceptions about the physical world, and about motion and force in particular, which are very rarely altered by traditional instruction (Champagne, Klopfer, Desena, & Squires, 1981; Minstrell, 1982).

These studies provide a rich body of descriptive information about the knowledge individuals display as they solve problems. For the most part, this work has included cross-sectional analyses, or "snapshots," of the knowledge states of different individuals at different levels of ability. In general, studies have not yet considered the questions of how individuals change from naive states to more expert states, and how to set up the instructional conditions under which students will learn to reason qualitatively about problems and to construct adequate problem representations. Our current work begins to address these more "prescriptive" questions.

Prescriptive Analyses of Problem-Solving Performance

Prescriptive models (Bruner, 1964; Reif, 1979) specify the knowledge required for novices to perform well on particular tasks, and do not necessarily include the knowledge actual experts rely on. Instead, they constitute the content we might wish to "prescribe" for students to learn. Such analyses are useful because it is not always desirable or possible to

teach experts' knowledge directly to novices. For one thing, experts have large repertoires of familiar patterns and automatized procedures that gradually develop over years of experience, and which may be impossible to teach directly. But in addition, novices' preconceptions are often incompatible with the ideas and language of the science to be learned. Novices' existing knowledge must be reorganized, restructured, or replaced, not simply appended to, and attempts to teach expert knowledge to novices may not address sufficiently issues related to the effects of prior knowledge on acquisition and retention of new knowledge.

Therefore, instead of attempting to teach novices to be experts, we are pursuing the more realistic goal of teaching novices a set of minimal, reliably effective rules and procedures which will allow them to perform competently, although differently from experts--more like "expert novices," perhaps. In place of the automatized procedures experts use, we identify explicit procedures which draw on the knowledge that is available to a novice. Also, the preconceptions of novices are taken into consideration by including preventive or compensatory procedures to block or catch common errors. Earlier work by Heller and Reif (1984) has shown that such explicit procedures for describing problems can be developed which do lead novices to perform competently.

Let us make clear that we neither expect nor want individuals to remain at this "expert novice" level for long periods of time after instruction. We instead assume that procedures will evolve spontaneously after instruction, under certain conditions becoming less explicit and more automatized and efficient. As Resnick (1976) has suggested, efficient instruction is not necessarily direct instruction in skilled performance. Rather, the aim can be to teach routines "that put learners in a good position to discover or invent efficient strategies for themselves." (p. 72)

We are assuming here that changes in knowledge do not stop simply because some external instructional intervention ceases. We know that, for example, children "invent" their own, more efficient, procedures for adding and subtracting numbers, procedures which differ from those they were originally taught (Groen & Resnick, 1977; Woods, Resnick, & Groen, 1975). We also know, of course, that we our abilities sometimes deteriorate, especially when we perform procedures infrequently. In an instructional study (Heller, 1984), we observed evidence of such changes in a procedure for determining the acceleration of a particle. In a few cases, steps in the procedure were dropped within an hour of instruction. This led to more efficient performance in some cases, and to errors in others. If we are to create conditions which lead to the evolution of competent, efficient performance, it is important for us to understand the kinds of spontaneous changes in knowledge which occur over time, and the relationship between those changes and the initial instructional content and conditions.

Prescriptive Theory of Problem Description

The prescriptive theory specifies a procedure which reliably leads to the construction of correct mechanics problem descriptions, as demonstrated by an earlier study conducted to validate this theory (Heller & Reif, 1984). Our current work is designed to teach one part of this model, the procedure for identifying the forces on objects. The procedure is summarized in Table 1.

Table 1 about here.

This procedure incorporates certain aspects of an expert's knowledge about the concept of force, but represents an explicit procedure which experts would not typically use. That is, the procedure is based on the notion of force as an <u>interaction</u>--in physics, a force is always exerted <u>on</u> one system

by another. In our procedure, attention is focussed on identifying systems that interact with the one being described, and only then identifying the force exerted by each such interacting system.

The procedure also incorporates a distinction between short-range and long-range interactions. Short-range interactions can be identified simply by determining everything that touches the system being described; every touching system exerts a short-range (or contact) force on the system. Long-range interactions involve systems which exert forces without any physical contact. In most typical mechanics problems, the only long-range force is the gravitational force exerted by the earth.

Finally, the prescriptive model includes information about the properties of forces, information which is required in order to determine the direction in which forces are exerted. This information is expressed in the form of explicit rules, such as, "A tension force is always exerted along the string-like system and away from the system being described." These rules are meant to evoke procedures for determining the direction of the force in question.

Theory of Instruction

While a theory of good performance is a necessary component of instruction, it is far from sufficient--such a prescriptive model only specifies what we want to teach, but not how we might teach it.

The instruction we are designing incorporates a particular model of learner-centered coaching which we refer to as "Evolving External Control Knowledge" (EECK). Our instructional materials consist of a series of subprograms which gradually transfer control over performance from the coach (in this case, the computer) to the learner. Initially, the learner simply acts as a spectator as the coach models the activity to be performed; eventually, the learner should acquire sufficient competence to take over full

responsibility for performing the activity. Between these extremes, the coach changes roles, from actively performing and modelling most of the work, to primarily serving as observer and critic; the learner proceeds from the role of novice, learning by watching the model and performing only simple steps of the activity, to performing all aspects herself, including making executive decisions and self-monitoring progress and adequacy of performance. Control knowledge evolves from initially residing outside of the learner to being completely internalized.

This model corresponds very closely to the ideas of "expert scaffolding" and "proleptic teaching" (Palincsar & Brown, in press; Rogoff & Gardner, in press; Wertsch & Stone, 1979) which are derived from Vygotsky's (1978) developmental theory.

> Proleptic means "in anticipation of competence" and in the context of instruction refers to situations where a novice is encouraged to participate in a group activity before she is able to perform unaided, the social context supporting the individual's efforts....
>
> Within these systems of tutelage, the child learns about the task at his own rate, in the presence of experts, participating only at a level he is capable of fulfilling - or a little beyond, thereby presenting a comfortable challenge. The distance between the level of performance a child can reach unaided and the level of participation he can accomplish when guided by another . . . is the child's zone of proximal development (Vygotsky, 1978), or "region of sensitivity to instruction" (Wood & Middleton, 1975).
>
> (Palincsar & Brown, in press, pp. 8-9)

Instructional Materials

We have begun to develop prototype versions of some of the instructional modules that will constitute the full sequence required for transferring control of the force identification procedure from coach to learner. These modules will eventually be implemented on an Apple Macintosh (or is it a Macintosh Apple?), but are currently implemented on a Commodore PET. Thus far

we have developed and begun to study the following three modules:

(1) Modelling of performance. At this level the learner watches the procedure being performed, controlling only the pace at which the steps are displayed. The coach specifies what step it is about to perform and then performs that step.

In the sample displays shown in Figure 1, the computer first presents the step to be performed (top), which in this case is to indicate the direction of the tension force on block A by the string. The learner then presses return to see the answer (bottom) which in this case is direction 9.

Figure 1 about here.

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(2) Proactive guidance. In the second module the coach provides complete external guidance, specifying what step should be performed and how to do it. After the learner performs that step, the coach checks to make sure it has been performed correctly, and does not allow the learner to proceed until performance is correct.

In the sample displays shown in Figure 2a and b, we see the coach first giving the learner information about how to determine the direction of the force (top) and how to indicate that direction by typing a number (bottom).

Figure 2 about here.

After the learner indicates a direction, the coach checks it and proceeds to explain how to do the next step only if the previous one was performed correctly (see Figure 2c).

(3) Retroactive checking. In the third module, the coach provides some external guidance, specifying what step should be performed, and then the learner performs that step. Instead of telling the learner how to do the

step, however, the coach guides the learner through self-checking of the learner's own performance. The coach then checks to make sure the learner's self-assessment is correct.

In the sample displays shown in Figure 3, we see the coach specifying what step the learner should perform next (top), and later see the coach guiding the learner through a check of the chosen direction. The coach allows the learner to proceed only if the both the performance and the check are performed correctly.

Preliminary Observations

We have observed nine subjects using the modules, including seven students currently enrolled in an introductory physics course at the University of California, Berkeley, and two who have not studied physics beyond the high school level. Verbal protocols were collected from each subject while performing force identification tasks before and after interacting with the program, as well as while interacting with the program, and all keypresses were recorded by the computer.

Each subject interacted with the three modules described above, in the order listed. Because these modules were not meant to transfer executive control to the learner, we did not necessarily expect the subjects to learn the entire procedure from such minimal exposure. Our goals were to formatively evaluate the program--to test whether the programs technically perform properly, and to gauge subjects' reactions to the materials, both with respect to the clarity of the messages and possible learning outcomes, even at this early stage. It was possible that subjects would learn something from observing the performance of the coach and from performing the steps of the program, even under external guidance, and our aim was to determine what aspects of the prescriptive model would be acquired fairly easily and which

aspects would not be readily internalized.

We are particularly interested in identifying possible relationships between changes in subjects' performance and features of both the model of performance and the model of instruction. On the basis of our preliminary observations, we see the following trends.

Results Related to Model of Performance

Force as interaction. Subjects seem to be internalizing the notion of force as a kind of interaction, as evidenced by the following: (1) Subjects mentioned which systems exerted the forces being identified more often after instruction than before. On the pretest, many subjects seemed to randomly identify individual forces rather than considering the systems exerting those forces. (2) Subjects identified normal and friction forces as a pair, one followed by the other, more often after instruction than before. Normal and friction forces are actually two components of the short-range force exerted by a surface, and we interpret contiguous identification as evidence of an awareness of the system responsible for the force.

Short-range/long-range distinction. Subjects seem to be internalizing the distinction between short- and long-range interactions as evidenced by the following: (1) explicit references to "short-range forces" or "things that touch," and to searching for same, more frequently after instruction than before; (2) a decrease in the number of errors of omitting short-range forces after instruction.

Persisting errors. Several subjects exhibited strong prior conceptions about causal relationships between force and motion--namely, that if a system's position or motion is influenced by another system, there must be a force reflecting that influence and, conversely, if a system's position or motion does not appear to be influenced by another system, a force exerted by that other system does not need to be included in the force diagram. These

strong convictions led subjects to (1) include extraneous forces (such as a force on the lamp by the ceiling) which they attributed to systems which neither touched nor exerted a direct long-range force without intervening physical contact, and (2) mention but then deliberately omit forces exerted by touching systems because they "don't matter." These prior ideas appear to override the incoming information in the instruction; these data confirm, once again, the strength and persistence of learners' prior knowledge about the physical world.

Results Related to Model of Instruction

Although the subjects differed widely in their ability to identify forces prior to instruction, they each were asked to use all three of the modules. The subjects' reactions tended to relate closely to their prior ability, as assessed on the pretest: higher ability subjects went through the more elementary modules (modelling and heavy proactive guidance) very quickly. They later complained that they did not find the programs useful because they were too trivial, but they speculated that someone just learning about forces would probably feel quite differently. In fact, lower ability subjects did appear quite absorbed in the lower level modules and tended to verbalize heavily about the procedure and to comment rather enthusiastically on the usefulness of the instruction, even during the purely modelled version.

These observations are promising indications that some features in the modules are differentially appropriate for individuals at different stages of learning. Because so few modules have been developed thus far, however, we cannot yet evaluate the effectiveness of our overall instructional strategy.

Effects of prior knowledge. We also observed that no subject ever adopted the entire procedure--in all cases, subjects' prior method was modified to incorporate some aspects of the prescribed procedure, but not

others. This is not surprising, since the modules we tested did not include those that will be designed to transfer executive control over the procedure to the learner. But we also interpret this as a reflection of the constructive nature of learning. If, as current cognitive theories suggest, the learning process consists primarily of restructuring and modification rather than deletion and replacement, then adoption of a new procedure, if it occurs at all, may take place gradually and only with extended practice under closely monitored conditions.

Conclusion

Our instructional studies are aimed at developing an understanding of the relationship between instructional conditions and learning outcomes. We are pursuing this goal by incorporating in our materials explicit theories of performance and instruction, so that we can assess the effects of systematically varying aspects of these theories.

A metaphor we like to use for the process of gaining expertise is that of a growing plant. Clearly, the tree that eventually grows in no way resembles the seed that was initially planted--but it does reflect the kind and quality of seed planted and the environmental conditions which were present early in the tree's life. Our interest is in identifying the instructional "seeds"--the explicit rules and procedures, as well as the initial instructional conditions--which are most likely to support the eventual growth of expert-like knowledge structures. In both cases, we cannot directly transform the seed into its fully developed form, but we can influence the rate and quality of spontaneous growth. We believe we have made some progress in developing some seeds of expertise, and will keep you informed of their growth in future reports.

References

Bruner, J. S. (1964). Some theorems on instruction illustrated with reference to mathematics. In E. R. Hilgard (Ed.), Theories of learning and instruction, the 63rd yearbook of the NSSE (Part 1). Chicago: Chicago University Press.

Champagne, A. B., Klopfer, L. E., Desena, A. T., & Squires, D. A. (1981). Structural representations of students' knowledge before and after science instruction. Journal of Research in Science Teaching, 18, 92-111.

Greeno, J. G. (1978). A study of problem solving. In R. Glaser (Ed.), Advances in instructional psychology (Vol. 1). Hillsdale, N.J.: Erlbaum.

Groen, G. J., & Resnick, L. B. (1977). Can preschool children invent addition algorithms? Journal of Educational Psychology, 69, 645-652.

Heller, J. I. (1984). Thinking about acceleration. Manuscript submitted for publication.

Heller, J. I., & Reif, F. (1984). Prescribing effective human problem-solving processes: Problem description in physics. Cognition and Instruction, 1, .

Larkin, J. H. (1977). Problem solving in physics (Tech. Report). Berkeley: University of California, Graduate Group in Science and Mathematics Education.

Larkin, J. H. (1980). Skilled problem solving in physics: A hierarchical planning approach. Journal of Structural Learning, 6, 121-130.

Larkin, J. H. (1982). The role of problem representation in physics. In D. Gentner & A. Collins (Eds.), Mental models. Hillsdale, N.J.: Erlbaum.

Larkin, J. H., McDermott, J., Simon, D. P., & Simon, H. A. (1980a). Expert and novice performance in solving physics problems. Science, 208, 1335-1342.

Larkin, J. H., McDermott, J., Simon, D. P., & Simon, (1980b). Models of competence in solving physics problems. Cognitive Science, 4, 317-345.

Minstrell, J. (1982). Explaining the "at rest" condition of an object. Physics Teacher, 20, 10-14.

Newell, A., & Simon, H. A. (1972). Human problem solving. Englewood Cliffs, N.J.: Prentice-Hall.

Palincsar, A. S., & Brown, A. L. (in press). Reciprocal teaching of comprehension-fostering and monitoring activities. Cognition and Instruction.

Reif, F. (1979). Theoretical and educational concerns with problem solving: Bridging the gaps with human cognitive engineering. In D. T. Tuma & F. Reif (Eds.), Problem solving and education: Issues in teaching and research (pp. 39-50). Hillsdale, N.J.: Erlbaum.

Resnick, L. B. (1976). Task analysis in instructional design: Some cases from mathematics. In D. Klahr (Ed.), Cognition and Instruction (pp. 51-80). Hillsdale, N.J.: Erlbaum.

Riley, M. S., Greeno, J. G., & Heller, J. I. (1983). Development of children's problem-solving ability in arithmetic. In H. Ginsburg (Ed.), The development of mathematical thinking (pp. 153-196). New York: Academic Press.

Rogoff, B., & Gardner, W. (in press). Guidance in cognitive development: An examination of mother-child instruction. In B. Rogoff & J. Lave (Eds.), Everyday dognition: Its development in social context. Cambridge, MA: Harvard University Press.

Simon, D. P., & Simon, H. A. (1978). Individual differences in solving physics problems. In R. Seigler (Ed.), Children's thinking: What develops? (pp. 325-348). Hillsdale, N.J.: Erlbaum.

Vygotsky, L. S. (1978). In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds. and trans.) Mind in society: The development of higher psychological processes. Cambridge: Harvard University Press.

Wertsch, J. V., & Stone, C. A. (February, 1979). A social interactional analysis of learning disabilities remediation. Paper presented at the International Conference of the Association for children with Learning Disabilities, San Francisco.

Wood, D., & Middleton, D. (1975). A study of assisted problem solving. British Journal of Psychology, 66, 181-191.

Woods, S. S., Resnick, L. B., & Groen, G. J. (1975). An experimental test of five process models for subtraction. Journal of Educational Psychology, 67, 17-21.

Table 1

Steps of Procedure for Identifying Forces

1. SYSTEM SELECTION

   Select a system **S** to be described.

2. SHORT-RANGE FORCES

   Identify a system that touches **S**.

   Indicate the force exerted ON **S** BY that system.

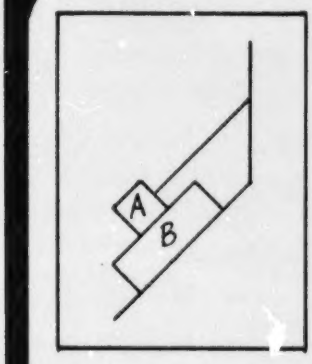
   Repeat for each system that touches **S**.

3. LONG-RANGE FORCES

   Identify a system that interacts with **S** from a distance.

   Indicate the force exerted ON **S** BY that system.

   Repeat if necessary. (Usually the earth is the only system exerting a long-range force.)



2. SHORT-RANGE FORCES

INDICATE THE TENSION FORCE
ON BLOCK A BY STRING

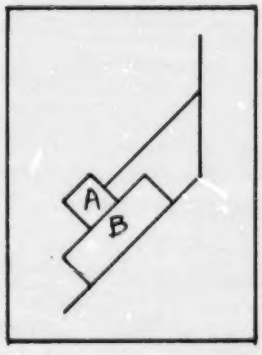
7 8 9
4 6
1 2 3

DIRECTION :

LABEL :

PRESS RETURN TO SEE
THE ANSWER

A



2. SHORT-RANGE FORCES

INDICATE THE TENSION FORCE
ON BLOCK A BY STRING

7 8 9
4 6
1 2 3

DIRECTION : 9

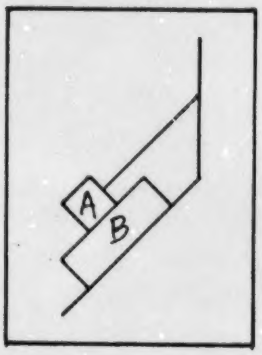
LABEL :

PRESS RETURN TO SEE
THE ANSWER

A

Figure 1. Sample displays from Modelling of Performance Module. Coach specifies what step it is about to perform (top), and learner repeatedly presses Return to see the outcome of performing that step (bottom).

(a)



2. SHORT-RANGE FORCES

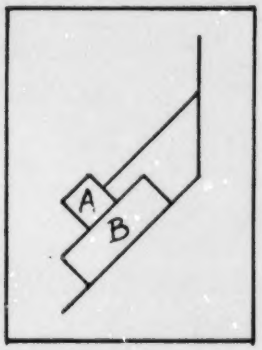
NAME A SYSTEM WHICH
TOUCHES BLOCK A
(OR 'NONE')
>STRING

A TENSION FORCE IS EXERTED
ALONG THE STRING AND
AWAY FROM THE SYSTEM
BEING DESCRIBED.

PRESS RETURN

A

(b)



2. SHORT-RANGE FORCES

INDICATE THE TENSION FORCE
ON BLOCK A BY STRING

7 8 9
4 6
1 2 3

DIRECTION: N

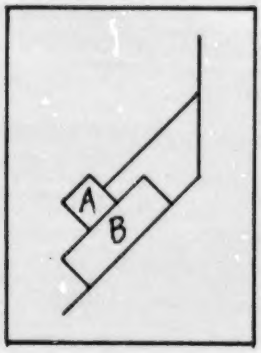
LABEL:

TYPE THE NUMBER WHICH
INDICATES THE DIRECTION OF
THE TENSION FORCE EXERTED
ON BLOCK A BY THE STRING.

A

Figure 2. Sample displays from Module with Proactive Guidance. Coach specifies what step should be performed next and how to perform it before learner performs that step (top, bottom). Coach proceeds to the next step only if learner performance of last step is correct (top of next page).

(c)



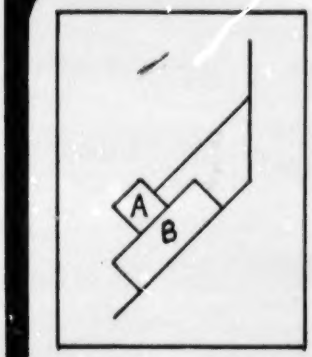
2. SHORT-RANGE FORCES

INDICATE THE TENSION FORCE
ON BLOCK A BY STRING

DIRECTION: 9

LABEL:

TYPE A ONE- OR TWO-CHARACTER LABEL FOR THIS FORCE.
A MEANINGFUL LABEL MIGHT BE 'TS' FOR TENSION FORCE EXERTED BY STRING.



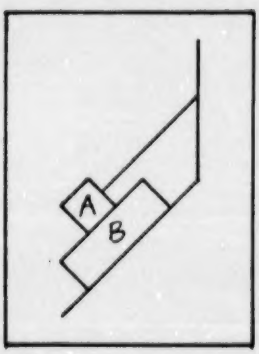
2. SHORT-RANGE FORCES

INDICATE THE TENSION FORCE
ON BLOCK A BY STRING

7 8 9
4 6
1 2 3

DIRECTION:
LABEL:

A



2. SHORT-RANGE FORCES

INDICATE THE TENSION FORCE
ON BLOCK A BY STRING

7 8 9
4 6
1 2 3

DIRECTION: 9
LABEL: T

T
A

A TENSION FORCE IS ALWAYS EXERTED ALONG THE STRING-LIKE SYSTEM AND AWAY FROM THE SYSTEM BEING DESCRIBED.
IS YOUR FORCE T IN THE RIGHT DIRECTION? (Y/N)

Figure 3. Sample displays from Module with Retroactive Checking. Coach specifies what step should be performed next (top) and guides the learner through self-checking of learner's own performance (bottom).